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# Fifteen-Year Results From a Grand Fir-Shasta Red Fir Spacing Study

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## Abstract

A 43-year-old, even-aged stand of advance reproduction of grand fir and Shasta red fir in central Oregon responded to release and thinning with diameter and height growth two to three times the prerelease rate. The response began the first growing season after the overstory was killed with 2,4-D. Diameter growth during the second and third 5-year periods after release increased significantly over that of the first 5 years. Differences in spacing had no effect on diameter growth during the first 5 years, but growth at the wider spacings increased considerably during the second and third periods. Increased growth after release suggested that saving true fir advance reproduction can be a desirable option, but the potential for losses from heart-rot should also be considered.

Keywords: Growth response, thinning effects, even-aged stands, release, grand fir, *Abies grandis*, Shasta red fir, *Abies magnifica*, Oregon (central), central Oregon.

## Introduction

Long-term growth and yield data from permanent plots are essential for developing yield tables for managed stands or for verifying stand simulation models. True firs are an important component of many mixed conifer forests in eastern Oregon and Washington, and many stands consist of a mature or overmature overstory with a suppressed understory of true fir saplings or poles. Little information is available on the growth potential of the fir understory after removal of the overstory and thinning to various spacings.

In 1970, a study was begun in a suppressed, even-aged stand of grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) and Shasta red fir (*A. magnifica* var. *shastensis* Lemm.) in central Oregon. The purpose was to obtain long-term data on growth of the two species at several initial spacings and under a progressive thinning schedule. This paper reports study results after 15 years. It supplements earlier reports of results for the first 10 years (Seidel 1977, 1983).

## Study Area and Methods

The study site is in the Pringle Falls Experimental Forest in the Deschutes National Forest near Bend, Oregon, on a north-facing, 13-percent slope at an elevation of about 5,600 feet. The soil is a well-drained Typic Cryorthent (Shukash series) developing in dacite pumice that orginated from the eruption of Mount Mazama about 6,500 years ago. It has an A1, AC, C1, C2 horizon sequence that is about 3 feet deep over the buried soil.

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Before study installation, the timber stand had an overstory of 75-year-old lodgepole pine (*Pinus contorta* Dougl. ex Loud.) with a 43-year-old grand fir-Shasta red fir seedling and sapling understory averaging about 4.5 feet in height. About 70 percent of the understory was less than 0.6 inch in diameter at breast height (d.b.h.), and average d.b.h. of measurable trees was about 1 inch. Site index of older red fir in the area, based on Schumacher's (1928) curves, indicates a height of 65 feet at age 50. Site index based on curves of DeMars and others (1970) shows a height of 120 feet at age 100. The lodgepole basal area averaged about 150 square feet per acre, and there were about 3,000 fir trees per acre in the understory.

The study area is in an *Abies shastensis/Chimaphila umbellata* plant community (Franklin and Dyrness 1973, p. 155). Ground vegetation is sparse and is primarily prince's pine (*Chimaphila umbellata* (L.) Bart.). Small amounts of other genera, such as *Arctostaphylos, Stipa, Carex,* and *Epilobium,* are also present.

The study has two closely related parts. One is an initial spacing experiment testing growth at four spacings (6, 12, 18, and 24 feet) in variable-area plots created by thinning in 1970. Each spacing is replicated twice, in a completely randomized design, to total eight plots. Twenty-four trees were selected for measurement in each plot; plot size, including buffer strips, ranged from 0.14 acre to 0.64 acre depending on spacing. No additional thinning will be done in these plots.

The second part of the study is a progressive thinning experiment with fixed-area plots similar to O'Conner's design (1935). Eight 0.25-acre plots were thinned to 6-foot spacing in 1970. The study plan calls for subsequent thinning based on diameter growth. When diameter growth of 10 percent of trees on all eight plots is at least 0.1 inch less than growth the previous year, six of the eight plots will be thinned to 12-foot spacing. When growth on the plots with 12-foot spacing slows to the same degree, four plots of the six will be thinned to 18-foot spacing. Thinning will continue in this pattern until there are two plots at each of the four spacings as in the variable-area plots. A completely randomized design is also used for these plots. Eventually volume growth and yield will be compared between the initially spaced, variable-area plots and the progressively thinned, fixed-area plots. None of the fixed-area plots have been thinned since 1970 so they retain the 6-foot spacing.

The lodgepole pine overstory was killed in 1970 with 2,4-D ([2,4-dichlorophenoxy] acetic acid) to release the fir understory without logging damage and to provide partial shade for a few years after release. Some fir seedlings near the plots were transplanted onto the plots to improve the spacing.

Height of all plot trees was measured to the nearest 0.1 foot, and d.b.h. of trees 0.6 inch or larger was measured to the nearest 0.05 inch in 1971, 1975, 1980, and 1985. Diameter was measured annually on a 10-percent sample of trees on the fixed-area plots. In 1976, 50 trees of each species were randomly chosen from the buffer strips and cut at ground level for measurements of diameter growth during the 5 years before release and the 5 years after release. In 1976, the 5-year prerelease height growth was measured by counting whorls of all trees in the variable-area plots and whorls of the 10-percent sample in the fixed-area plots. In 1975, the total height and diameter at 4-foot intervals up the stem were measured on 15 trees per plot to calculate an equation expressing cubic volume of the entire stem inside bark as a function of diameter and height. This equation was used to compute plot volumes from the measurements taken in 1971, 1975, 1980, and 1985.

Table 1—Characteristics of grand fir-Shasta red fir plots after thinning in 1970 and in 1975, 1980, and 1985

| Year, plot, and spacing | Species composition: Grand fir | Species composition: Red fir | Total trees | Trees less than 0.6 inch d.b.h. | | Quadratic mean diameter 1/ | Average height | Basal area | Total volume |
|---|---|---|---|---|---|---|---|---|---|
| | —Percent— | | —Number per acre— | | Percent | Inches | Feet | Square feet per acre | Cubic feet per acre |
| After thinning, 1970: | | | | | | | | | |
| Fixed-area plots— | | | | | | | | | |
| 6 by 6 feet | 59 | 41 | 1,169 | 817 | 70 | 1.2 | 4.6 | 2.8 | 20.6 |
| Variable-area plots— | | | | | | | | | |
| 6 by 6 feet | 81 | 19 | 1,200 | 975 | 81 | 1.2 | 3.8 | 1.7 | 11.5 |
| 12 by 12 feet | 79 | 21 | 304 | 158 | 52 | 1.2 | 5.6 | 1.2 | 7.7 |
| 18 by 18 feet | 92 | 8 | 134 | 103 | 77 | .9 | 4.3 | .2 | 1.1 |
| 24 by 24 feet | 71 | 29 | 78 | 63 | 83 | 1.0 | 4.1 | .1 | .5 |
| 1975: | | | | | | | | | |
| Fixed-area plots— | | | | | | | | | |
| 6 by 6 feet | 59 | 41 | 1,114 | 498 | 45 | 1.5 | 6.7 | 8.5 | 65.4 |
| Variable-area plots— | | | | | | | | | |
| 6 by 6 feet | 81 | 19 | 1,200 | 800 | 67 | 1.5 | 5.3 | 5.4 | 38.3 |
| 12 by 12 feet | 79 | 21 | 304 | 95 | 31 | 1.8 | 8.0 | 3.6 | 25.4 |
| 18 by 18 feet | 92 | 8 | 134 | 61 | 46 | 1.4 | 6.5 | .8 | 5.6 |
| 24 by 24 feet | 71 | 29 | 76 | 33 | 43 | 1.3 | 6.0 | .4 | 2.5 |
| 1980: | | | | | | | | | |
| Fixed-area plots— | | | | | | | | | |
| 6 by 6 feet | 60 | 40 | 1,039 | 280 | 27 | 2.2 | 8.4 | 19.9 | 173.6 |
| Variable-area plots— | | | | | | | | | |
| 6 by 6 feet | 81 | 19 | 1,200 | 550 | 46 | 1.9 | 8.5 | 12.8 | 100.5 |
| 12 by 12 feet | 80 | 20 | 298 | 44 | 15 | 2.6 | 10.1 | 9.3 | 81.8 |
| 18 by 18 feet | 92 | 8 | 132 | 11 | 8 | 2.1 | 9.1 | 3.0 | 24.8 |
| 24 by 24 feet | 69 | 31 | 76 | 11 | 15 | 2.0 | 8.3 | 1.4 | 10.2 |
| 1985: | | | | | | | | | |
| Fixed-area plots— | | | | | | | | | |
| 6 by 6 feet | 60 | 40 | 1,003 | 115 | 11 | 2.7 | 10.9 | 37.1 | 386.7 |
| Variable-area plots— | | | | | | | | | |
| 6 by 6 feet | 81 | 19 | 1,200 | 450 | 38 | 2.1 | 7.8 | 22.5 | 195.4 |
| 12 by 12 feet | 80 | 20 | 291 | 19 | 7 | 3.2 | 12.6 | 16.2 | 175.5 |
| 18 by 18 feet | 92 | 8 | 131 | 0 | 0 | 3.3 | 12.7 | 7.8 | 85.4 |
| 24 by 24 feet | 68 | 32 | 75 | 5 | 7 | 3.0 | 11.5 | 3.5 | 33.7 |

1/ All trees 0.6 inch d.b.h. and larger.

Average height of trees on the eight fixed-area plots was 4.6 feet after thinning and ranged from 3.8 to 5.6 feet on the variable-area plots (table 1). Average d.b.h. of trees of measurable size was about 1 inch. Of the trees in the fixed-area plots, 59 percent were grand fir as compared with 81 percent in the variable-area plots.

Differences in diameter and height growth among species, periods, and initial spacings were analyzed for the variable-area plots using split-split plot analyses of variance in a completely randomized design at the 0.05 probability level. Whole plot treatments were spacings, split-plot treatments were species, and time periods were the split-split plot factor. Tukey's test was used to determine significant differences among treatment means. Height growth was also subjected to analysis; height before release and thinning and 5-year prerelease height growth were used as covariates. No analyses were applied to data from the fixed-area plots because those plots all have the same 6-foot spacing.

Table 2—Periodic annual increment and mortality of grand fir and Shasta red fir saplings during 3 5-year measurement periods after release and thinning in 1970 when trees were 43 years old

| Age, plot, and spacing | Diameter growth 1/ | Basal area growth: Net | Basal area growth: Mortality | Basal area growth: Gross | Total volume growth: Net | Total volume growth: Mortality | Total volume growth: Gross |
|---|---|---|---|---|---|---|---|
| | Inches 2/ | Square feet per acre 2/ | | | Cubic feet per acre 2/ | | |
| From age 43 to 48 (1971-75): | | | | | | | |
| Fixed-area plots— | | | | | | | |
| 6 by 6 feet | 0.15±0.01 | 1.13±0.18 | 0.01±0.001 | 1.14±0.18 | 8.9±1.7 | 0.1±0.01 | 9.0±1.7 |
| Variable-area plots— | | | | | | | |
| 6 by 6 feet | .15±.05 | .74±.69 | 0 | .74±.69 | 5.4±4.9 | 0 | 5.4±4.9 |
| 12 by 12 feet | .16±.01 | .50±.09 | 0 | .50±.09 | 3.6±1.0 | 0 | 3.6±1.0 |
| 18 by 18 feet | .16±.05 | .14±.07 | 0 | .14±.07 | .9± .5 | 0 | .9± .5 |
| 24 by 24 feet | .16±.01 | .06±.01 | 0 | .06±.01 | .4± .1 | 0 | .4± .1 |
| From age 48 to 53 (1976-80): | | | | | | | |
| Fixed-area plots— | | | | | | | |
| 6 by 6 feet | .17±.01 | 2.28±.29 | .08±.01 | 2.36± .30 | 21.6±3.8 | .7±.2 | 22.3±4.0 |
| Variable-area plots— | | | | | | | |
| 6 by 6 feet | .18±.01 | 1.47±1.02 | 0 | 1.47±1.02 | 12.4±9.4 | 0 | 12.4±9.4 |
| 12 by 12 feet | .22±.03 | 1.14± .33 | .03±.01 | 1.17± .34 | 11.3±4.6 | .2±.08 | 11.5±4.8 |
| 18 by 18 feet | .23±.01 | .44± .14 | 0 | .44± .14 | 3.9±1.8 | 0 | 3.9±1.8 |
| 24 by 24 feet | .20±.02 | .20± .07 | 0 | .20± .07 | 1.6± .6 | 0 | 1.6± .6 |
| From age 53 to 58 (1981-85): | | | | | | | |
| Fixed-area plots— | | | | | | | |
| 6 by 6 feet | .16±.01 | 3.43± .27 | .05±.01 | 3.48± .27 | 42.6±5.9 | .3±.09 | 42.9±5.9 |
| Variable-area plots— | | | | | | | |
| 6 by 6 feet | .12±.01 | 1.95±1.15 | 0 | 1.95±1.15 | 19.0±14.1 | 0 | 19.0±14.1 |
| 12 by 12 feet | .18±.01 | 1.46± .31 | .03±.01 | 1.49± .32 | 18.8± 6.3 | .1±.01 | 18.9± 6.3 |
| 18 by 18 feet | .27±.03 | .96± .26 | 0 | .96± .26 | 12.1± 5.1 | 0 | 12.1± 5.1 |
| 24 by 24 feet | .24±.01 | .42± .09 | 0 | .42± .09 | 4.7± 1.6 | 0 | 4.7± 1.6 |

1/ Arithmetic mean diameter growth of trees 0.6 inch D.B.H. or larger at beginning of each 5-year period and living through the period.

2/ Mean ± standard error.

## Results

### Diameter Growth

Release had a marked effect on the rate of diameter growth of the fir understory. The average growth of both species during the 5 years before release (measured on trees cut in buffer strips) was about 0.04 inch per year. Growth increased nearly threefold, to 0.11 inch per year, in the 5 years after release. The response occurred during the first year and averaged 0.13 inch.

During the first 5-year period, diameter growth was not affected by differences in spacing: annual growth averaged 0.16 inch on the 12-, 18-, and 24-foot spacings and 0.15 inch on the 6-foot spacing (table 2). On the eight fixed-area plots, which remained at 6-foot spacing, periodic annual diameter growth averaged 0.15 inch, and there was no significant difference between grand fir (0.14 inch per year) and red fir (0.16 inch per year).

During the second 5-year period, diameter growth increased significantly ($P < 0.05$) above that of the first period. Increases ranged from 20 percent at the 6-foot spacing to 44 percent at the 18-foot spacing. Differences among spacings were still not significant, although growth at the 12- and 18-foot spacings was 0.22 to 0.23 inch per year compared with 0.18 inch at the 6-foot spacing (table 2).

During the third 5-year period, diameter growth averaged over all spacings was about the same as during the second period (0.20 vs. 0.21 inch per year). Although overall growth was similar among periods, growth at the 6- and 12-foot spacings decreased 16 to 33 percent; growth at the 18- and 24-foot spacings increased 15 to 20 percent compared with the second period. Differences among spacings were significant ($P < 0.01$). Growth at the 6-foot spacing (0.12 inch per year) was significantly less than growth at the 18- or 24-foot spacing (0.27 and 0.24 inch per year)(table 2). Diameter growth of trees on the fixed-area plots (all at the 6-foot spacing) was essentially constant during all three periods (0.15 to 0.17 inch per year). As during the first two periods, no significant differences in diameter growth were found between grand fir and red fir. Diameter growth shown in table 2 may not agree with differences between mean diameters at the beginning and end of growth periods shown in table 1 because average diameters at each measurement are based on trees 0.6 inch d.b.h. or larger at the time, but growth is based only on trees of measurable size in 1970, 1975, and 1980.

## Height Growth

Height growth did not differ significantly between the first two periods, but increased significantly ($P < 0.05$) during the third period. Although statistically significant, the change in the rate of height growth was small; it increased from about 0.41 foot per year during the first two periods to 0.52 foot per year during the third (averaged over the four spacings). No significant differences in height growth were found among spacings or between species during any of the three periods. During the third period, however, growth differences approached significance at the 5-percent level because of the faster growth at the 18- and 24-foot spacings. Average annual growth was slowest at the 6-foot spacing during all periods and fastest at the 12- and 18-foot spacings during the first two periods (table 3). During the third period, height growth at the two widest spacings increased considerably to about 0.7 foot annually.

The trees responded to release the first growing season after release, in contrast to a delay of 5 years for suppressed red firs in California (Gordon 1973). The height growth rate doubled from about 0.2 foot annually before release to about 0.4 foot per year after release. Even after release, however, the rate of height growth (0.4 foot per year) did not increase greatly during the first 10 years and was comparable to the growth rate of 5-year-old grand fir planted in the same general area (Seidel 1985a). Although the rate of height growth is still relatively slow, growth appears to be accelerating during the third period at the two widest spacings and on the fixed-area plots at the 6-foot spacing.

## Basal Area and Volume Growth

Growth in both basal area and total cubic volume on the fixed-area plots was small during the first 5 years but increased significantly ($P < 0.05$) from the first to the second period and again from the second to the third period as more trees reached measurable size (table 2). Annual volume increment more than doubled during the second period, from 9.0 to 22.3 cubic feet per acre, and nearly doubled again during the third period to 42.9 cubic feet per acre. Basal area and volume growth on the variable-area plots showed the expected response to spacing—progressively less growth as spacing increased because of fewer trees per unit area. Even though the growth rate differed widely, possibly because on one variable-area plot at a 6-foot spacing only one-third of the trees were of measurable size in 1980 compared to about three-fourths of the trees on the other plot, differences in growth rates among spacings were not significant. At this time, growth on the fixed-area plots is therefore more representative of the true growth potential at the 6-foot spacing than is growth on the 6-foot-spaced variable-area plots. This disparity should decrease in the future when all trees on all plots are measured for basal area and volume growth.

## Table 3—Periodic annual diameter and height growth after release, by species, spacing, and growth period

| Time period, plot, and spacing | Diameter growth 1/ | | | Height growth 2/ | | |
|---|---|---|---|---|---|---|
| | Grand fir | Red fir | Both species | Grand fir | Red fir | Both species |
| | Inches 3/ | | | Feet 3/ | | |
| First period (1971-75): | | | | | | |
| Fixed-area plots-- | | | | | | |
| 6 by 6 feet | 0.14±0.01 | 0.16±0.01 | 0.15±0.01 | 0.41±0.03 | 0.35±0.03 | 0.38±0.03 |
| Variable-area plots-- | | | | | | |
| 6 by 6 feet | .15±.01 | .22±.01 | .15±.005 | .33±.08 | .24±.12 | .30±.08 |
| 12 by 12 feet | .16±.01 | .19±.01 | .16±.005 | .47±.06 | .51±.09 | .48±.03 |
| 18 by 18 feet | .16±.05 | .20± 0 | .16±.05 | .45±.05 | .50±.03 | .45±.04 |
| 24 by 24 feet | .16±.01 | .18± 0 | .16±.005 | .40±.06 | .33±.12 | .38±.07 |
| Second period (1976-80): | | | | | | |
| Fixed-area plots-- | | | | | | |
| 6 by 6 feet | .16±.01 | .18±.01 | .17±.01 | .35±.02 | .33±.02 | .33±.02 |
| Variable-area plots-- | | | | | | |
| 6 by 6 feet | .16±.01 | .19±.01 | .18±.01 | .20±.06 | .28±.04 | .24±.07 |
| 12 by 12 feet | .21±.04 | .27±.05 | .22±.03 | .48±.02 | .42±.16 | .48±.04 |
| 18 by 18 feet | .22±.03 | .25±.04 | .23±.01 | .50±.05 | .65±.05 | .51±.05 |
| 24 by 24 feet | .20±.01 | .19±.08 | .20±.02 | .46±.06 | .45±.09 | .46±.08 |
| Third period (1981-85): | | | | | | |
| Fixed-area plots-- | | | | | | |
| 6 by 6 feet | .16±.01 | .17±.01 | .16±.01 | .48±.05 | .51±.03 | .49±.04 |
| Variable-area plots-- | | | | | | |
| 6 by 6 feet | .12±.02 | .13±.01 | .12±.01 | .23±.11 | .40±.08 | .26±.10 |
| 12 by 12 feet | .18±.01 | .18±.01 | .18±.01 | .45±.01 | .54±.06 | .46± 0 |
| 18 by 18 feet | .26±.02 | .27±.07 | .27±.03 | .73±.07 | .68±.22 | .73±.08 |
| 24 by 24 feet | .23±.01 | .27±.02 | .24±.01 | .60±.09 | .72±.19 | .65±.13 |

1/ Arithmetic mean diameter growth of trees 0.6 inch d.b.h. or larger at beginning of each 5-year period and living through the period.

2/ Based on growth of all trees living through each 5-year period.

3/ Mean ± standard error.

The effects of some 40 years of suppression on growth and yield can be estimated by comparison of the basal area and volume data obtained in this study with yield estimates for unsuppressed grand or white fir given by Cochran (1979). For example, when the study was established (age 43), the fixed-area plots at the 6-foot spacing had about 1.2 percent of the net basal area and 0.5 percent of the net cubic volume of unsuppressed stands of the same age and site index. The basal area growth rate of these plots during the first 5-year period after release was 25 percent of the growth rate of unsuppressed stands, while volume growth was 5 percent of the unsuppressed rate. After 15 years, in 1985, net basal area on these study plots was about 15 percent of the unsuppressed stands and net cubic volume was about 6 percent. During the third period after release, basal area growth was equal to that of the unsuppressed stands and volume growth increased to 25 percent of unsuppressed stands.

## Mortality

During the 15 years of this study, 255 trees died; 11 during the first period, 70 during the second, and 74 during the third. All but 8 of the 111 that died during the first 5 years were transplanted seedlings. During the second and third periods, about 25 percent of the mortality appeared to be caused by *Armillaria* sp. Most of the remaining mortality was in trees less than 3 feet tall with very small crowns. No snow damage was observed after release and thinning, except for a few trees with small crowns that were growing in dense clumps before thinning.

# Discussion

After 15 years, the results of this study give land managers an estimate of the growth rates that can be expected after suppressed true fir sapling stands are released from overstory competition and thinned to various spacings. After release, the increase in diameter and height growth rates of two to four times the prerelease rate is typical of other studies in the Western United States (Ferguson and Adams 1979, Gordon 1973, McCaughey and Schmidt 1982, Seidel 1985b). Increased growth rates sometimes occur the first year after release; sometimes they are delayed several years. In either case, silviculturists can be confident of an accelerated growth rate within 5 years after release if the trees are vigorous and live crown ratios are at least 50 percent.

The diameter growth response to spacing is now typical of such studies—greater growth as spacing between trees increases. This relation was not present during the first 5-year period after release, when diameter growth at all spacings was about the same, but became evident during the second period and was more pronounced during the third period. The basal area and cubic volume growth data after 15 years showed the potential of sapling-size true fir stands to respond to release quickly even though suppressed for 40 or more years.

Although there is now ample evidence that suppressed true fir advance reproduction has the capacity to considerably increase diameter, height, and volume growth rates after release and thinning, the possibility of future volume losses caused by Indian paint fungus (*Echinodontium tinctorium* E & E) should also be considered by managers when evaluating the potential of suppressed true fir for future crop trees. This fungus is responsible for most of the heartrot decay in old-growth grand fir stands. Aho (1977) found that this fungus alone causes about 70 percent of the board-foot decay volume in the Blue Mountains of eastern Oregon and Washington. Guidelines for reducing losses from heartrot based on tree vigor, number of wounds, degree of suppression, and presence of the disease in the overstory have been prepared by Filip and Aho (1978) and Filip and others (1983).

A decision to save and manage the advance reproduction requires the use of logging methods and slash-disposal techniques designed to reduce loss and damage to the understory. Procedures to accomplish this objective that have proved successful are given by Aho and others (1983), Barrett and others (1976), Gottfried and Jones (1975), and Gravelle (1977).

## Metric Equivalents

| | |
|---|---|
| 1 acre | = 0.405 hectare |
| 1 inch | = 2.54 centimeters |
| 1 foot | = 0.3048 meter |
| 1 mile | = 1.61 kilometers |
| 1 square foot | = 0.0929 square meter |
| 1 square foot per acre | = 0.2296 square meter per hectare |
| 1 tree per acre | = 2.47 trees per hectare |
| 1 cubic foot | = 0.0293 cubic meter |
| 1 cubic foot per acre | = 0.0700 cubic meter per hectare |

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